

Phantom Limb Pain

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Many patients awake from the anesthetic after an amputation believing that the operation has not been performed. Their continued sense of the lost limb is so real that not until they lift the bed sheets to see it do they realize it has been cut off. This startling realization has little effect on the reality of the limb they experience, and in some cases may even intensify the sensations that define it. Mitchell (1871) coined the term *phantom limb* to describe the persisting sensory awareness of a limb after amputation.

A distinction is usually made between the painful and nonpainful phantom limb (Melzack & Wall, 1988). The most salient property of the nonpainful phantom is its tingling, "pins and needles" or *paresthetic* quality, but sensations of temperature, posture, length, volume, and movement are also very common (T. S. Jensen & Rasmussen, 1994). Recent studies estimate the incidence of the nonpainful phantom at approximately 80% to 100% (T. S. Jensen & Rasmussen, 1994). For many amputees, however, a distressing problem is phantom limb pain (R. A. Sherman, 1989). Many patients report a painful intensification of the paresthesias (i.e., dysesthesias) that define the nonpainful phantom limb. Some sufferers describe bouts of paroxysmal shooting pain that travel up and down the limb. Others report the phantom to be in a cramped or otherwise unnatural posture that gives rise to excruciating pain. Many amputees describe the

pain in the phantom limb as indistinguishable from the pain they experienced in the limb prior to amputation. In still others, the phantom may be immobile or paralyzed so that attempts to move it generate pain. Finally, the phantom is often the seat of an intense burning pain as if the hand or foot were being held too close to an open flame. Frequently, amputees suffer from several types of pain (T. S. Jensen & Rasmussen, 1994). A recent survey based on several thousand amputees reveals that more than 70% continue to experience phantom limb pain of considerable intensity more than 25 years after amputation (R. A. Sherman, C. J. Sherman, & Parker, 1984). Equally striking is the low success rate of treatments for phantom limb pain: In the long term only 7% of patients are helped by the more than 50 types of therapy used to treat phantom limb pain (R. A. Sherman, 1989). This intractability reflects our ignorance about the mechanisms that contribute to phantom limb pain.

This chapter evaluates the joint influence of peripheral neurophysiological factors and higher order cognitive and affective processes in triggering or modulating a variety of phantom limb experiences, including pain. The first section outlines one way in which the sympathetic nervous system may influence phantom limb pain. A model involving a sympathetic-efferent somatic-afferent cycle is presented to explain fluctuations in the intensity of sensations referred to the phantom limb. In the second section, the model is extended to explain the puzzling finding that only *after* amputation are thoughts and feelings capable of evoking referred sensations to the (phantom) limb. Whereas phantom pains and other sensations frequently are triggered by thoughts and feelings, there is no evidence that the painful or painless phantom limb is a symptom of a psychological disorder. The available literature on coping with phantom limb pain is then reviewed. In the third section, the concept of a pain "memory" is introduced and described with examples. The data show that pain experienced prior to amputation may persist in the form of a memory referred to the phantom limb causing continued suffering and distress. It is argued that two independent and potentially dissociable memory components underlie the unified experience of a pain memory. This conceptualization is evaluated in the context of the surgical arena, raising the possibility that under certain conditions postamputation pain may, in part, reflect the persistent central neural memory trace left by the surgical procedure. Preemptive analgesia and other preventive approaches to the management of phantom limb pain are briefly reviewed. In the final section, the immobile or paralyzed phantom is presented along with recent evidence that a simple, nonpharmacological intervention may prove helpful in restoring a sense of movement to the phantom limb. Treatment implications and options are presented at the end of each section.

SYMPATHETIC NERVOUS SYSTEM CONTRIBUTIONS TO PHANTOM LIMB EXPERIENCE

Phantom Limb Pain

A controversy has arisen over the origin of the phantom limb. In an attempt to find a single explanatory mechanism, theories have focused on only one aspect of phantom limb experience and have ignored or discounted others (Melzack & Wall, 1988). The cause has been sought in the activity of primary afferent fibers, spinal cord cells, and supra-spinal sensory nuclei (T. S. Jensen & Rasmussen, 1994; Melzack & Wall, 1988). A review of these mechanisms is beyond the scope of this chapter. The interested reader is referred to several recent publications for more detail (Devor, 1994; T. S. Jensen & Rasmussen, 1994; R. A. Sherman, Devor, Jones, Katz, & Marbach, 1997). Another class of theory has attempted to account for the phantom solely on the basis of psychological and emotional processes (Szasz, 1975). It is becoming increasingly clear, however, that the phantom limb cannot be explained by a unitary mechanism—whether peripheral, central, or psychological (Melzack, 1989). This conceptualization proposes that the simultaneous outputs of neural networks in widespread regions of the brain combine to produce the various qualities of human experience—including phantom limb experience.

Sherman and Arena (1992) have also argued that phantom limb pain is not a unitary syndrome, but a symptom class, with each class subserved by different etiologic mechanisms. For example, one class of phantom limb pain, which is characterized by a cramping quality, is associated with electromyographic (EMG) spike activity in muscles of the stump whereas burning phantom limb pain shows no such association (R. A. Sherman & Arena, 1992). Katz and Melzack (1990) have identified a class of phantom limb pain that resembles in quality and location a pain experienced in the limb before amputation. Although the precise physiological mechanisms that underlie these somatosensory pain memories are unknown, the presence of preamputation pain clearly is a necessary condition for these phantom pains to develop. Another class of phantom limb pain may come about through involvement of the sympathetic nervous system. The interested reader is referred to a more detailed review of the role of the sympathetic nervous system in phantom limb pain (Katz, 1996).

Evidence That the Sympathetic Nervous System Is Involved in Phantom Limb Pain

Evidence of sympathetic involvement among amputees with phantom limb pain comes from studies that pharmacologically block (Livingston, 1938, 1943) or surgically interrupt (Bailey & Moersch, 1941; Kallio, 1950) the

sympathetic supply to the involved limb producing at least temporary alleviation of pain. Long-term relief of phantom limb pain has been reported with propranolol, a beta-adrenergic blocking agent, although these reports are uncontrolled and unblinded (Ahmad, 1984; Marsland, Weekes, Atkinson, & Leong, 1982; Oille, 1970). An open trial of propranolol in six (nonamputee) patients with pain from peripheral nerve injuries showed very little benefit (Scadding, Wall, Wynn Parry, & Brooks, 1982). Electrical or mechanical stimulation of the lumbar sympathetic chain produces intense pain referred to the phantom limb (Echlin, 1949; Noordenbos, 1959), whereas sensations are referred to the abdomen or flank in pain patients without amputation (Noordenbos, 1959).

Regional sympathetic hyperactivity has also been hypothesized to contribute to the development of phantom limb pain through excessive vasoconstriction and sweating at the stump and surrounding regions (Livingston, 1943). The condition may spread centrally from the stump to involve the phantom limb. Hyperalgesia (heightened pain) and allodynia (pain arising from gentle touch) may be referred to the phantom limb upon stimulation of the stump whether or not the stump is painful or shows signs of trophic or vascular changes (Doupe, Cullen, & Chance, 1944; Livingston, 1938). The characteristic qualities of superficial burning pain and deep aching pain may provide additional evidence of sympathetic nervous system involvement (Doupe et al., 1944). However, just as some sympathetically maintained pains occur in the absence of regional sympathetic abnormalities (Campbell, Meyer, Davis, & Raja, 1992), not all patients with phantom limb pain due to sympathetic nervous system involvement would be expected to show signs of abnormal sympathetic nervous system activity at the stump (e.g., trophic changes, abnormal sympathetic reflexes and sweating, alterations in stump blood flow). This possibility suggests that the abnormality associated with sympathetically maintained pains of this type does not reside in the sympathetic nervous system but in the afferent supply of the involved extremity (Schott, 1993; Treede, Davis, Campbell, & Raja, 1992). The absence of signs of sympathetic nervous system abnormality points to the importance of diagnostic sympathetic blocks, the phentolamine test, or regional infusions of guanethidine to ascertain the presence of sympathetically maintained pain.

Even when sympathetic nervous system abnormalities are present, their relationship to pain in the stump and pain in the phantom is not always clear-cut (Sunderland, 1968). For example, Livingston (1938) reported cases of amputees with phantom limb pain who also showed abnormalities in sweating and large temperature differences between the stump and contralateral intact limb but who did not complain of stump pain. Local anesthetic infiltration into the sympathetic ganglia was followed by relief

of phantom limb pain, a sense of warmth and relaxation in the phantom, and a reversal of the vasomotor, sudomotor, and trophic changes at the stump—all of which often extended well beyond the duration of action of the local anesthetic. Despite the correlation between the restoration of normal sympathetic functioning and the relief of phantom limb pain, it remains unclear whether the sympathetic abnormalities were responsible for the pain or whether both were caused by a common third factor (e.g., reduced sympathetic transmitter release).

Nyström and Hagbarth (1981) carried out microneurographic recordings of activity from skin and muscle nerve fascicles in two amputees with phantom limb pain. One patient had sustained a below-knee amputation and suffered from intense cramping pain referred to the phantom foot. Recordings from muscle nerve fascicles in the peroneal nerve showed that although bursts of activity in sympathetic fibers were accentuated by the Valsalva maneuver, the phantom pain remained unchanged, suggesting that the pain was not dependent on sympathetic activity. The second patient had undergone amputation of his left hand at the wrist secondary to extensive lacerations following an agricultural accident. Microneurographic recordings were taken from a skin nerve fascicle in the left median nerve at the wrist. In both patients, tapping the neuroma at the stump evoked marked neural activity, afterdischarge, and an intensification of the phantom limb pain. Interestingly, although local anesthetic infiltration into the tissue of the stump surrounding the neuroma abolished (or reduced) the tap-induced increase in neural activity and phantom limb pain, in neither patient was the spontaneous or background neural activity and phantom limb pain changed. In the light of recent work by Devor and colleagues (Devor, 1994; Devor, Jänig, & Michaelis, 1994), the ongoing neural activity that persisted after lidocaine infiltration may well have originated in the dorsal root ganglion and propagated antidromically to reach the recording electrode in the stump (Devor, 1994).

Further evidence of a possible connection between the sympathetic nervous system and pain after amputation comes from a single-blind study (Chabal, Jacobson, Russell, & Burchiel, 1992) of nine amputees with stump pain ($n = 5$) and concomitant phantom limb pain ($n = 3$) who received successive perineuromal injections of normal saline (0.5 ml), epinephrine (5 μ g in 0.5 ml normal saline), and lidocaine (1 ml 1%). Within 1–2 seconds of injection of epinephrine all patients reported an increase in the intensity of local stump pain, although only one of the three patients noted an increase in phantom limb pain.

The quality of the pain following injection of epinephrine was described as “poorly localized shooting or electric shocklike” whereas the area of discomfort increased from baseline. Four patients remarked that the limb

was "on fire." Lidocaine injection significantly decreased but did not abolish the pain. Five patients who also received a control injection of subcutaneous epinephrine (5 μ g in 0.5 ml normal saline) in a region distant from the neuroma reported a localized, minor stinging of approximately 1–2 seconds in duration that was described as distinctly different from the pain experienced in response to perineuromal injection of epinephrine.

Sympathetic Nervous System Activity at the Stump Correlates With Phantom Limb Pain

Despite frequent assertions that the sympathetic nervous system is involved in the production and maintenance of phantom limb pain, surprisingly few studies have actually examined peripheral sympathetic nervous system activity at the stump and contralateral limb. Sliosberg (1948) studied 141 amputees and found that the stump was cooler than the intact limb in 94 patients, but he did not relate the temperature difference to the presence or absence of phantom limb pain. Kristen, Lukeschitsch, Plattner, Sigmund, and Resch (1984) reported that a "patchy asymmetrical temperature" distribution of stump thermograms was significantly more frequent among stump pain sufferers than in patients who were free from stump pain, but thermograms were no different for patients with or without phantom limb pain.

In contrast, R. A. Sherman and colleagues (R. A. Sherman, 1984; R. A. Sherman & Bruno, 1987) observed a negative correlation between temperature at the stump and the presence of burning, tingling, or throbbing phantom limb and stump pain, indicating that reduced blood flow to the stump is associated with increased levels of pain. Repeated measurements of the same patients on different occasions revealed that lower temperatures at the stump relative to the contralateral limb were associated with greater intensities of phantom limb and stump pain, suggesting that the reduced blood flow was in some way causally tied to the pain. However, in the majority of cases, the relationship between phantom pain and limb temperature was confounded by coexisting stump pain, so that it is not possible to unambiguously attribute the presence of phantom limb pain to altered blood flow at the stump.

Katz (1992) followed up this line of inquiry and compared skin conductance and surface skin temperature of the stump and contralateral limb in amputees reporting phantom limb pain (Group PLP), nonpainful phantom limb sensations (Group PLS), or no phantom limb at all (Group No PL). The results showed that although mean skin temperature was lower at the stump than the contralateral limb in all groups, the difference was significant for Groups PLP and PLS, but not Group No PL. Stump-intact

limb temperature differences in excess of -1°C were associated with the presence of a phantom limb in the absence of concomitant stump pain.

These results suggest that the presence of a phantom limb, whether painful or painless, is related to the sympathetic-efferent outflow of cutaneous vasoconstrictor fibers in the stump and stump neuromas. The related finding that stump skin conductance responses over time correlated significantly with the intensity of phantom limb paresthesias, but not other qualities of sensation, supports the hypothesis (outlined later) of a sympathetic-efferent somatic-afferent mechanism involving both sudomotor and vasoconstrictor fibers. The most parsimonious explanation of these findings is that the paresthetic or dysesthetic component of the phantom limb may be triggered by sympathetic-efferent activity.

Psychophysical Correlates of Phantom Limb Paresthesias

Although a normal phantom occurs whenever nerve impulses from the periphery are blocked or otherwise removed (Wall, 1981), it is also true that direct stimulation of the amputation stump frequently exaggerates the tingling or paresthetic quality of sensation typical of the painless phantom limb (Carlen, Wall, Nadvorna, & Steinbach, 1978). Careful questioning of amputees reveals that the nonpainful phantom limb is not perceived as a static phenomenon. The paresthetic quality of sensation, which defines the phantom limb percept, is in a constant state of flux, with changes occurring in intensity, body part, or both. For example, Katz et al. (1989) reported on a subject whose phantom sensations consisted of a "numbness" that defined a region including the lateral three toes. Within this circumscribed area, he experienced rapid "waves of numbness" that increased and decreased the intensity of the involved phantom parts.

One mechanism that has been proposed to account for the paresthetic component of the phantom limb is a cycle of sympathetic-efferent somatic-afferent activity (Katz, 1992; Katz, France, & Melzack, 1989). As shown in Fig. 19.1, stump skin conductance levels correlate significantly over time with the intensity of phantom limb paresthesias. It is hypothesized that changes in the intensity of phantom limb paresthesias reflect the joint activity of cholinergic (sudomotor) and noradrenergic (vasomotor) postganglionic sympathetic fibers on primary afferents located in the stump and stump neuromas (Fig. 19.2). Release of acetylcholine and norepinephrine from postganglionic sympathetic fibers produces transient vasoconstriction and heightened skin conductance responses. As well, neurotransmitter release onto apposing peripheral fibers trapped in stump neuromas increases primary afferent discharge. This information is transmitted rostrally where it gives rise to referred phantom sensations upon

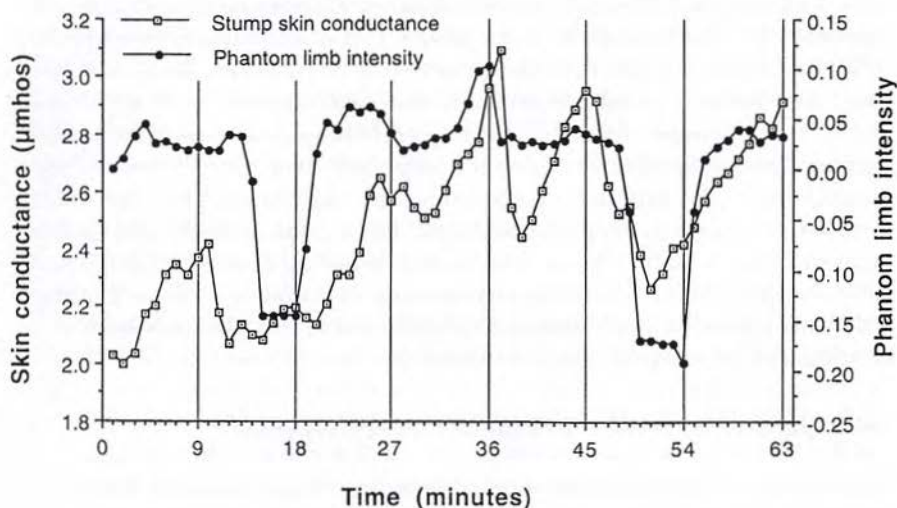


FIG. 19.1. A minute-by-minute plot of the relationship between stump skin conductance and the intensity of nonpainful phantom limb paresthesias for a subject with an amputation above the knee. Skin conductance was continuously measured at the stump over a 63-minute period while the subject monitored the intensity of the phantom limb by turning a dial. Phantom limb intensity ratings have been transformed so that a value of 0.0 represents the intensity at the start of the session and deviations from zero correspond to increases and decreases in phantom limb intensity. Each data point represents a mean of 30 values consecutively sampled at 2-second intervals. Note that changes in the intensity of paresthesias (described by the subject as increases and decreases in "numb" sensations referred to the phantom toes) occur in concert with changes in stump skin conductance. From Katz, France, and Melzack, 1989. Copyright 1989 by Elsevier Press. Adapted with permission.

reaching central structures subserving the amputated parts of the limb. The moment-to-moment fluctuations in the intensity of phantom limb paresthesias reported by many amputees may, in part, reflect a cycle of sympathetic-efferent somatic-afferent activity. Increases in the intensity of phantom limb paresthesias would follow bursts of sympathetic activity and decreases would correspond to periods of relative sympathetic inactivity (Katz, 1992; Katz et al., 1989). If central sensitization has also developed either through prior injury, trauma during amputation, or peripheral inflammation, or, if the sympathetic-sensory coupling involves nociceptors (Roberts, 1986) the sensation may be one of dysesthesia. Direct support for this hypothesis would require that changes in the intensity of phantom limb paresthesias (or dysesthesias) be correlated with microneurographic recordings from postganglionic sympathetic and primary afferent fibers in

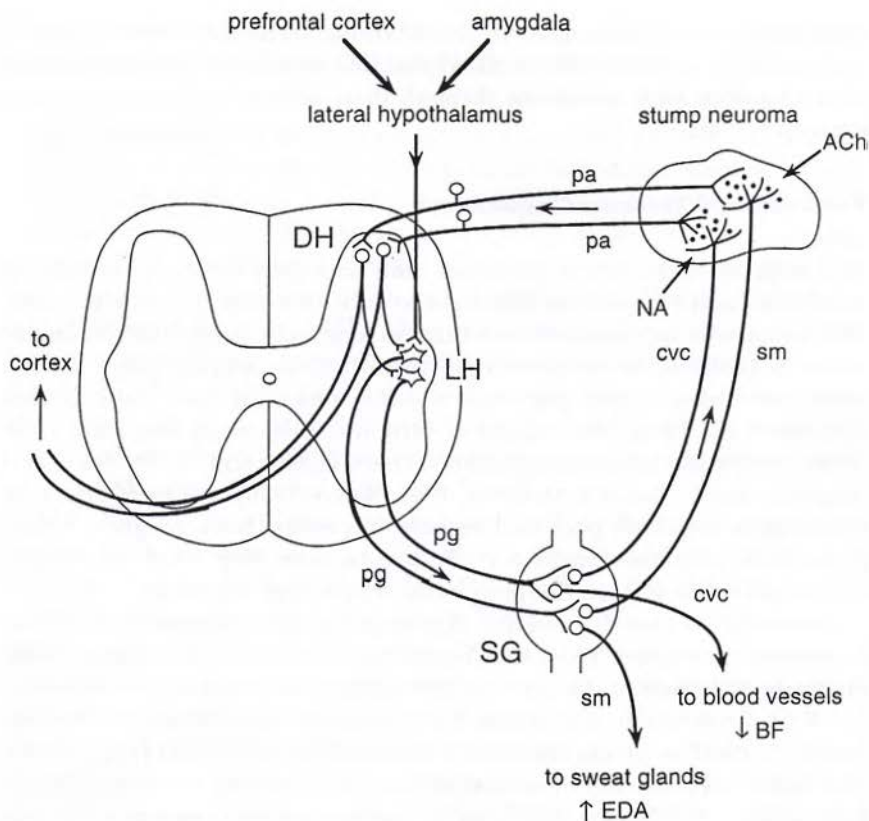


FIG. 19.2. Schematic diagram illustrating a mechanism of sympathetically generated phantom limb paresthesias. Spontaneous activity or excitatory inputs descending from cortex (e.g., due to the perception of a salient event, loud noise, thought, feeling, etc.) increase the discharge rate of preganglionic (pg) sympathetic neurons with cell bodies in the lateral horn (LH) of the spinal cord and terminals in the sympathetic ganglion (SG). These neurons excite postganglionic noradrenergic (NA) cutaneous vasoconstrictor (cvc) and cholinergic (ACh) sudomotor (sm) fibers that impinge on effector organs (vascular smooth muscle and sweat glands) in the stump and on sprouts from large-diameter primary afferent (pa) fibers that have been trapped in a neuroma. The release of ACh and NA on effector organs results in increased electrodermal activity (EDA) and decreased blood flow (BF) to the stump. Release of these chemicals in the neuroma activates primary afferents that project to spinal cord dorsal horn (DH) cells subserving the amputated parts of the limb. These neurons, in turn, feed back to the preganglionic sympathetic neurons and project rostrally where the impulses contribute to the perception of phantom limb paresthesias. If DH cells have been sensitized due to injury, or nociceptive primary afferents are activated, then the perception may be dysesthetic.

amputation stump neuromas. In the following section, this mechanism is elaborated to explain how psychological and emotional processes might alter phantom limb sensations through their actions on the sympathetic nervous system.

Treatment and Treatment Implications

The majority of studies of phantom limb pain lack the rigorous control conditions and adequate sample sizes to conclude with certainty that specific treatments are more effective than no treatment or placebo treatment. There is evidence of an adrenergic sympathetic-sensory coupling mechanism underlying stump pain and possibly phantom limb pain as well (Chabal et al., 1992). The results of early studies showing that local anesthetic infiltration into the sympathetic chain (Livingston, 1938, 1943) and sympathectomy (Bailey & Moersch, 1941; Kallio, 1950) at least temporarily relieve phantom limb pain also suggest that sympathetic ganglion blocks or surgical sympathectomies are effective because they block the release of norepinephrine from the peripheral sympathetic terminals.

It should be noted, however, that pain relief in response to a local anesthetic sympathetic block may be due to factors other than sympathetic blockade. Diffusion of the agent to the dorsal roots resulting in small-fiber block or a systemic action of the local anesthetic are limitations of diagnostic sympathetic blocks that reduce the specificity of the test (Raja, 1993). The lack of permanency of sympathectomy for phantom limb pain (Bailey & Moersch, 1941; Kallio, 1950) may be due to a variety of factors including inadequacy of diagnosis, extent of sympathectomy, surgical skill, and confusion about anatomy (Campbell, Raja, Selig, Belzberg, & Meyer, 1994). The finding that beta-adrenergic receptor blockade does not seem to be effective in relieving phantom limb pain (Scadding et al., 1982) is consistent with the negative results of propranolol for treatment of sympathetically maintained pain in nonamputees (Campbell, Raja, & Meyer, 1993).

Phantom limb pain and stump pain respond well to epidural or spinal administration of local anesthetics or opioids (Jacobson & Chabal, 1989; Jacobson, Chabal, & Brody, 1989; Jacobson, Chabal, Brody, Mariano, & Chaney, 1990). Although the relevant assessments to determine the presence of sympathetically maintained pain were not established in these studies, the possibility remains that the continuous sympathetic blockade achieved by epidural infusions of local anesthetic agents may prove effective in the management of patients with sympathetically maintained pain (Campbell et al., 1994). To date, neither the phentolamine test (Raja, Treede, Davis, & Campbell, 1991), nor regional infusions of guanethidine have been tried for phantom limb pain. Raja (1993) has published guidelines for evaluating patients suspected of having sympathetically maintained pain.

PSYCHOLOGICAL AND EMOTIONAL CONTRIBUTIONS TO PHANTOM LIMB EXPERIENCE

It is not surprising that amputees suffering with phantom limb pain exhibit higher than normal levels of psychological and emotional distress. Depression (Caplan & Hackett, 1963; Lindesay, 1985; R. A. Sherman, C. J. Sherman, & Bruno, 1987; Shukla, Sahu, Tripathi, & Gupta, 1982), anxiety (Parkes, 1973; Shukla et al., 1982), and other forms of psychopathology are common (Morgenstern, 1970; Parkes, 1973; Shukla et al., 1982; Steigerwald, Brass, & Krainick, 1981). Moreover, amputees with severe phantom limb pain score higher on psychological inventories measuring depression (Lindesay, 1985) and neuroticism (Morgenstern, 1970) than do amputees who have little or no pain. However, amputees with phantom limb pain report higher levels of overall disability than do patients with musculoskeletal pain (Marshall, Helmes, & Deathe, 1992).

The co-occurrence of phantom limb pain and psychological disturbance has led to three conclusions: (a) Pain is a symptom of a psychological disorder (Parkes, 1973; Szasz, 1975), (b) psychological disturbance is a consequence of pain (R. A. Sherman & Bruno, 1987), or (c) the two are causally unrelated (Caplan & Hackett, 1963). At present, the consensus is that there is no difference in the prevalence rates of pain of psychological origin among amputees and the general population. There is no evidence to suggest that surgical amputation predisposes an individual to develop pain of psychological origin, nor that patients who undergo amputation are at greater risk for developing such pain. However, a prospective study has yet to be conducted in which preoperative measures of psychological and emotional functioning are obtained sufficiently prior to amputation so as to avoid the confounding effects of preamputation pain and hospitalization.

Psychodynamic Explanations

Psychodynamic explanations of phantom limb phenomena have been advanced as evidence of the amputee's difficulty in adapting to the mutilated state (Frazier & Kolb, 1970; Parkes, 1973; Parkes & Napier, 1975; Szasz, 1975). Denial (of the loss or the associated affect) and repression are the most common defense mechanisms proposed to explain the presence of a painless phantom (Szasz, 1975), painful phantom (Parkes, 1973; Parkes & Napier, 1975; Stengel, 1965; Szasz, 1975), and various alterations in the form of the phantom limb (Abramson & Feibel, 1981; Weiss, 1958).

Though often elegantly formulated, psychodynamic explanations are not consistent with the accumulation of physiological and psychological data. For example, many amputees become profoundly depressed after surgery, yet phantom pain and other sensations persist. The co-occurrence

of depression and pain is inconsistent with the role of denial because the intense negative affect implies awareness, if not acceptance, of the loss (Caplan & Hackett, 1963). In fact, for many amputees, the affect associated with the loss is so overwhelming that it cannot be contained and seems to "spill over" into the phantom thereby increasing the intensity of paresthesias (Simmel, 1959).

There are other inconsistencies between psychodynamic theory and empirical evidence. Apparently healthy individuals who, by all objective measures, have adjusted to the amputation continue to report the presence of a phantom years after amputation (Simmel, 1959). Phantoms that occur after injury to the central nervous system (CNS) (e.g., when sensory and motor nerve roots are torn from the spinal cord or the spinal cord is transected) are similar to amputation phantoms in quality of sensation even though the real limb(s) is still present but totally anesthetic and paralyzed. One would not expect denial of the loss of function to produce a phantom defined by paresthesias (Weinstein, 1962). Phantoms do not develop if the process of sensory loss is gradual, as in leprosy (Price, 1976), yet there should be as great a need for denial in these cases. Finally, procedures that temporarily block the supply of afferent impulses from reaching the CNS (e.g., anesthetic nerve blocks, blood pressure cuff occlusion) reliably result in the perception of a phantom limb that persists until the flow of afferent input has been restored (Melzack & Bromage, 1973; Wall, 1981). Under these circumstances, it is difficult to see the need of a phantom limb to fulfill the putative ego-protective function of defending the individual from a loss.

Although denial is more commonly associated with diseases that have no visual evidence of infirmity (Caplan & Hackett, 1963), the foregoing does not imply that denial of the loss, affect, illness, or future implications plays no part in the overall adaptation to amputation (Rosen, 1950). Patients may demonstrate their denial of the importance of these realities in a variety of ways (Bradway, Malone, Racy, Leal, & Poole, 1984; Turgay & Sonuvar, 1983), but these do not include having a phantom. For the vast majority of amputees, the presence of a phantom limb—painful or painless—is not a symptom of a psychological disorder.

Characterological Disturbances

In addition to the role of specific defense mechanisms in the genesis of phantom limb pain, it is postulated that phantom limb pain may be psychologically determined by characterological disturbances such as "compulsive self-reliance" and "rigidity" (Parkes, 1973). With the exception of a recent review (R. A. Sherman et al., 1987), the idea that patients with persisting phantom limb pain are rigid and exhibit compulsively self-reliant

personality characteristics has been uncritically accepted by researchers and clinicians working in the field of phantom limb pain (Dawson & Arnold, 1981; Dernham, 1986; Lundberg & Guggenheim, 1986; Shukla et al., 1982) despite the absence of empirical evidence to support this view.

The association between the presence of pain and psychological distress (e.g., depression and anxiety) or particular personality traits or styles (e.g., rigidity and compulsive self-reliance) may be influenced by biased sampling procedures so that the characteristics of a select group of patients (e.g., those referred to a pain center) come to define the population at large (Merskey, 1989; R. A. Sherman et al., 1987). Sherman et al. suggested that the low success rate of most treatments for phantom limb pain serves as a deterrent to all but the most persistent or self-reliant individuals. Long after less assertive patients have given up actively seeking help, these sufferers of phantom limb pain continue to search for relief despite repeated failures. According to Sherman et al., this self-selection bias explains the tendency for individuals with "compulsively self-reliant" personality characteristics *and* phantom limb pain to dominate the clinical picture of the typical patient with phantom limb pain.

Recent studies indicate that among an unselected sample of amputees, those with phantom limb pain, painless phantom limb sensations, or no phantom limb at all cannot be distinguished by their scores on personality, depression, or anxiety inventories (Katz & Melzack, 1990, 1991). Moreover, there are no significant intergroup differences in scores on a questionnaire designed to measure psychological "rigidity" as defined by a tendency to persist in behaviors that were effective at one time, or in a particular situation, but no longer are adequate to accomplish current goals (Katz & Melzack, 1990).

Coping With Phantom Limb Pain

Coping with chronic pain may be defined as the thoughts and actions people engage in in their efforts to manage pain on a daily basis (Katz, Ritvo, Irvine, & Jackson, 1996). These diverse efforts include interventions as global as cognitive-behavior therapy and other self-management programs developed to help patients cope with a multitude of problems associated with pain to specific strategies designed to manage the sensory intensity of a discrete episode of pain. In addition to the burden of pain, patients must contend with many secondary lifestyle changes that inevitably arise when pain becomes chronic. Among these downstream effects are loss of employment and income, mood disturbances such as depression and anxiety, changes in the marital relationship and family dynamics, and a reduction in social and leisure activities (Hitchcock, Ferrell, & McCaffery, 1994).

The literature on phantom limb pain spans more than 100 years, yet we know very little about the coping efforts and outcomes of amputees with phantom limb pain. To date, only a single study has evaluated use of coping strategies in patients with phantom limb pain (Hill, 1993). The Coping Strategies Questionnaire (CSQ; Rosenstiel & Keefe, 1983) was administered to 60 male, upper- or lower-extremity amputees. A principal components analysis yielded three factors (cognitive control, helplessness, and pain denial) accounting for 68% of the variance. The helplessness factor, made up of three subscales (increasing activity level, praying or hoping, and catastrophizing) of the CSQ accounted for approximately 20% of the variance in pain report and psychological distress.

These results are consistent with what is known about pain coping in other chronic pain populations, namely, patients who catastrophize fare worse than those who do not (M. P. Jensen, Turner, Romano, & Karoly, 1991). Factor analytic or principal component techniques often yield a factor that invariably includes the negative-thinking characteristic of catastrophizing (e.g., helplessness, pain control and rational thinking, self-control and rational thinking). In general, these factors tend to be strongly correlated with depression, measures of physical impairment, and poor psychosocial adjustment.

For example, a reduction in catastrophizing was associated with less pain and improved psychosocial functioning following either cognitive-behavioral or operant behavioral therapy for low back pain (Turner & Clancy, 1986). In another study (Flor, Behle, & Birbaumer, 1993), the degree of catastrophizing was reduced significantly from pre- to posttreatment among patients who improved but not among patients who did not. In contrast, improvement was not accompanied by a strengthening of adaptive self-statements and beliefs. The association between lower pain and a reduction in the use of catastrophizing but not a strengthening of adaptive self-statements and beliefs suggests that maladaptive cognitions may have a stronger influence on negative outcomes than the utilization of adaptive coping strategies. In other words, it may be more important *not to catastrophize* than to engage in positive self-statements. This is a challenging area for future research and treatment development given the tendency for certain qualities of phantom limb pain to occur episodically and unpredictably (Hill, 1993). These parameters are likely to contribute to a sense of helplessness and lack of personal control.

Primary pain prevention and early detection of individuals at risk for developing chronic pain is of paramount importance. Keefe, Salley, and Lefebvre (1992) advocate use of longitudinal designs in which subjects are identified and assessed in terms of coping strategies prior to the development of chronic pain. Following these individuals over time would clarify the relationship between pain coping strategies and the development of

persistent pain. Future research might best accomplish this objective by targeting patient populations, such as amputees, at relatively high risk for developing long-term pain problems.

Psychological and Emotional Processes Influence Phantom Limb Experience

As reviewed previously, the idea that emotional and psychological processes can cause pain traditionally has been tied to the notion of psychopathology. However, it is becoming increasingly clear that under certain circumstances pain may be triggered by these processes in psychologically healthy individuals as well. Although instances of psychologically or emotionally triggered pain and psychopathology may be present in the same amputee, their co-occurrence should not be taken as *prima facie* evidence of a causal link.

It is commonly accepted that anxiety or stress influences pain perception and subsequent behavior (Merskey, 1989). The aggravation or alleviation of pain referred to phantom body parts also may be mediated in part by psychological processes that alter anxiety levels (Kolb, 1954). Phantom breast pain after mastectomy is provoked by emotional distress in 6% of women 3 weeks after surgery and in 29% 1 year later (Krøner, Krebs, Skov, & Jørgensen, 1989). Fifty percent of lower-extremity amputees report that attacks of phantom limb pain are triggered by emotional distress (T. S. Jensen, Krebs, Nielsen, & Rasmussen, 1985) as long as 7 years after amputation (Krebs, T. S. Jensen, Krøner, Nielsen, & Jørgensen, 1985). A combination of progressive relaxation training and EMG biofeedback of stump and forehead muscles produces significant reductions of phantom limb pain and anxiety (R. A. Sherman, 1976) that are sustained for up to 3 years (R. A. Sherman, Gall, & Gormly, 1979). Finally, stress levels and pain intensity ratings sampled over a 180-day observation period correlate significantly for most amputees (Arena, R. H. Sherman, & Bruno, 1990).

There are also examples of psychological or emotional processes precipitating transient but profound alterations in the quality and intensity of phantom limb sensations. These processes include hypnosis (Schilder, 1950), concentration (Morgenstern, 1964; Riddoch, 1941), distraction (Parkes, 1973), relaxation (R. A. Sherman, 1976; R. A. Sherman et al., 1979), fright (Henderson & Smyth, 1948), forceful reminders of the events that led to amputation (Simmel, 1956), the sight of other amputees (Simmel, 1956), and witnessing cruel and violent acts (Pilowsky & Kaufman, 1965; Stengel, 1965). One amputee, interviewed by the present writer, described his reaction to an accident involving his wife by reporting "... goose bumps and cold shivering down the phantom [leg]. It went through me. Everything emotional will get you that." Another amputee stated, "It's like everything I feel goes there—the good and the bad."

A Centrally Triggered Sympathetic-Efferent Somatic-Afferent Mechanism

The material presented earlier indicates that cognitive and affective processes reliably trigger transient pains or sensations referred to the phantom limb. The model schematically represented in Fig. 19.2 outlines a mechanism through which cognitive and affective processes associated with higher cortical and limbic centers may alter phantom limb sensations. The reciprocal connections between cortical, limbic, and lateral hypothalamic structures are well documented (Brodal, 1981; Smith & DeVito, 1984). The lateral hypothalamus is involved in the control and integration of neural activity associated with affectively charged behavior (Brodal, 1981; Melzack & Casey, 1968; Smith & DeVito, 1984) and has direct projections to the lateral horn of the spinal cord. The intensity of phantom limb paresthesias and dysesthesias may thus be modulated by higher brain centers involved in cognitive and affective processes via a multisynaptic network of descending inputs that impinges on preganglionic sympathetic neurons producing diffuse peripheral autonomic discharge and activation of primary afferent fibers located in stump neuromas.

Occasionally, the effects of intense affect (e.g., fright, horror) are experienced diffusely over the entire body as *cutis anserina* associated with pilomotor contraction (i.e., "goose bumps"). Among amputees, however, a more frequent occurrence is that the perception of less salient events and emotions precipitate these sensations throughout only the phantom limb. The tendency for affectively charged and psychologically meaningful experiences to be referred to the phantom limb, but not to other parts of the body, is consistent with two lines of evidence suggesting that the threshold for impulse generation is lower both in regenerating primary afferents in the stump and in deafferented central cells subserving the phantom limb than it is in the intact nervous system.

First, regenerating sprouts, which are trapped in a neuroma, are exceedingly sensitive to the postganglionic sympathetic neurotransmitters noradrenaline (Wall & Gutnick, 1974) and acetylcholine (Diamond, 1959), and they discharge rapidly when these substances are present. In contrast, intact peripheral fibers do not show this chemosensitivity, and thus have a higher threshold compared with regenerating sprouts. Second, the loss of afferent nerve impulses (deafferentation) resulting from amputation produces a disinhibition of cells in the dorsal horn and more rostral sensory structures giving rise to the perception of a phantom limb (Melzack & Loeser, 1978; Wall, 1981). This consequence of deafferentation implies that the threshold for detecting sympathetically triggered afferent impulses arising from stump neuromas should be lower than at other, intact body sites because stump impulses would be subject to less inhibition upon

reaching the spinal cord. This fits well with the observation that the threshold for detecting sensations in the phantom limb during stimulation of the stump is lower than at the site of stimulation itself (Carlen et al., 1978).

Another possibility is that amputation leads to increased expression of alpha-1 adrenergic receptors located on mechanoreceptors or nociceptors (Campbell et al., 1992) in stump neuromas. This hypothesis would explain the perception of phantom limb paresthesias or dyesthesias in the absence of regional sympathetic hyperactivity. Taken together, these observations may explain the puzzling finding that only after amputation does the (phantom) limb become the site of affectively or cognitively triggered sensations.

The suggestion that the perception of phantom limb sensations may reflect the activity of postganglionic sympathetic fibers on stump primary afferents is obviously not meant to imply that paresthesias arise only from a peripheral source. Blocking the afferent supply to a body region is sufficient to produce the experience of a painless phantom defined by paresthesias (Melzack & Bromage, 1973; Wall, 1981) and electrical stimulation of the medial lemniscal pathway gives rise to the sensation of paresthesias referred to the territory subserved by the cells being stimulated (Tasker, Organ, & Hawrylyshyn, 1982). Moreover, it is likely that through repeated activation, neural circuitry is strengthened among brain regions subserving cognitive, affective, and sensory processes so that phantom limb sensations and pain may be triggered by thoughts and feelings in the absence of primary afferent feedback from peripheral structures (LeDoux, 1989; Leventhal, 1982).

Implications for Treatment of Phantom Limb Pain

Given that cognitive and affective processes may trigger or exacerbate phantom limb pain, it is of the utmost importance that patients be prepared prior to amputation for the presence of a phantom limb. Patient education programs and treatment of stress prior to and after amputation have become standard practice (Butler, Turkal, & Seidl, 1992; McGrath & Hillier, 1992; R. A. Sherman, 1989). Patients who are ill prepared psychologically for amputation suffer needlessly with phantom limb pain and concern about their sanity (Solomon & Schmidt, 1978).

It is noteworthy that mental stress and anxiety not only provoke transient increases in the intensity of phantom limb sensations and pain (Arena et al., 1990; R. A. Sherman, 1976; R. A. Sherman et al., 1979), but they also induce reflex-bursting activity in cutaneous sudomotor and vasomotor sympathetic fibers (Delius, Hagbarth, Hongell, & Wallin, 1972; Hagbarth, Hallin, Hongell, Torebjörk, & Wallin, 1972). Moreover, distraction or attention diversion (and intense concentration) that reduces phantom limb pain (Morgenstern, 1964; Parkes, 1973) also diminishes peripheral sympa-

thetic nervous system activity (Hagbarth et al., 1972). These findings provide support for the model shown in Fig. 19.2 and suggest that relaxation training and other cognitive strategies directed at anxiety reduction and increasing self-control may be effective in reducing phantom limb pain in certain amputees. To date controlled studies of this nature have not been carried out.

PAIN MEMORIES IN PHANTOM LIMBS

A striking property of phantom limb pain is the presence of a pain that existed in a limb prior to its amputation (Melzack, 1971). This class of phantom limb pain is characterized by the persistence or recurrence of a previous pain, has the same qualities of sensation, and is experienced in the same region of the limb as the preamputation pain (Katz & Melzack, 1990). Case studies of amputees have revealed pain "memories" of painful diabetic foot ulcers, bedsores, gangrene, corns, blisters, ingrown toenails, cuts and deep tissue injuries, and damage to joints and bony structures. As well, the phantom limb may assume the same painful posture as that of the real limb prior to amputation, especially if the arm or leg had been immobilized for a prolonged period.

The proportion of amputees who report similar pain before and after amputation may be as high as 79% (Katz & Melzack, 1990). Pain memories in phantom limbs appear to be less common when there has been a discontinuity, or a pain-free interval, between the experience of pain and amputation. This is consistent with the observation that relief of phantom limb pain by continuous epidural blockade for 3 days before amputation decreases the incidence of phantom limb pain 6 months later (Bach, Noreng, & Tjélliden, 1988). Furthermore, compared with pain that is temporally noncontiguous with amputation, pain experienced at or near the time of amputation has a higher probability of persisting into the phantom limb (T. S. Jensen et al., 1985; Katz & Melzack, 1990).

Pain also persists in patients with deafferentation that does not involve amputation. In these conditions, the involved body part is still present but it is devoid of sensibility due to an interruption in the supply of sensory (afferent) information (i.e., deafferentation). Brachial plexus avulsions, in which the sensory nerve roots supplying the arm and hand are torn from the spinal cord, often produce pain that is felt in the deafferented and anesthetic region (T. S. Jensen & Rasmussen, 1994; Reisner, 1981). Similarly, patients with spinal cord injuries (Berger & Gerstenbrand, 1981; Conomy, 1973) may complain of pain referred to body parts below the level of the transection. For example, Nathan (1962) described a patient who continued to feel the pain of an ingrown toenail after a complete

spinal cord break. As well, patients undergoing spinal anesthesia (Van Bogaert, 1934; Wallgren, 1954) and those with injuries of the brachial plexus or spinal cord sometimes report that a limb is in the same uncomfortable, often painful, posture it was in prior to the injury of block. These postural phantom sensations do not usually persist beyond several days and in most cases are at least temporarily reversed by competing visual inputs that reveal a dissociation between the real and felt limb(s).

Painful and nonpainful sensations also persist or recur after surgical removal or deafferentation of body structures other than the limbs, such as breasts (Krøner et al., 1989), teeth (Marbach, 1978; Sicuteri, Nicolodi, Fusco, & Orlando, 1991), and internal and special sense organs. Ulcer pain has been reported to persist after subtotal gastrectomy with removal of the ulcer (Gloyne, 1954). Patients have reported labor pain and menstrual cramps after total hysterectomy (Dorpat, 1971), rectal pain (Boas, Schug, & Acland, 1993) and hemorrhoids (Oveson, Krøner, Ørnsholt, & Bach, 1991) after removal of the rectum and anus, the burning pain of cystitis after complete removal of the bladder (Brena & Sammons, 1979), and the pain of a severely ulcerated cornea after enucleation of an eye (Minski, 1943).

Taken together, these case reports and studies of amputees reveal that pain memories are not merely images or cognitive recollections; they are direct experiences of pain that resemble an earlier pain in location and quality. They are perceptually complex experiences that may even involve information from multiple sensory modalities including visual, olfactory, tactile, and motor components that had accompanied the original experience. The precise details of the experiences of pain involve localization, discrimination, affect, and evaluation—that is, all the dimensions of perceptual experience—and these properties are a function of integrated brain activity. It is likely that the outputs of sensitized spinal cells activate the neural structures in the brain that subserve memories of earlier events.

Separate Somatosensory and Cognitive Memory Components Underlie Pain Memories

A closer examination of the phenomenon suggests that the experience of a pain memory reflects the joint activity of two separate memory subsystems with properties and functions specialized for processing somatosensory and cognitive (declarative) information respectively. The somatosensory memory component consists of the same, or very similar, neural circuitry that was activated by the peripheral input prior to amputation. It is a higher order functional unit that codes the temporal and spatial patterning of nerve impulses specifying the body part, quality of sensation, and intensity of the somatosensory experience.

The cognitive memory component contains declarative information related to when and in what context the preamputation pain occurred as well as *meta-information about* the body part, quality of sensation, and intensity of the preamputation experience. The declarative information contained in the cognitive component provides the unique, personal meaning associated with the somatosensory component and provides a basis for the identifying label and response (e.g., "my pain," a corn, diabetic ulcer, etc.). The determination that a current sensory impression has occurred before involves a process of recognition: One must know, or have access to knowledge about, what one has (and therefore has not) previously experienced in order to state whether two experiences separated in time are the same or different.

Evidence of a Double Dissociation Between Somatosensory and Cognitive Components

There is evidence that it is possible to demonstrate a double dissociation of these two memory components. Evidence of the cognitive component in the absence of the somatosensory component is common and occurs whenever amputees recall details about a preamputation pain (e.g., its duration, quality of sensation, location, intensity) without also reexperiencing the somatosensory qualities of that pain (Katz & Melzack, 1990). Dissociation of the opposite kind is not as common and is more difficult to demonstrate, because without the knowledge (i.e., contents of the cognitive memory component) of what one has felt in the past, the reactivation of the somatosensory qualities of a past pain would be perceived as novel and therefore would not be recognized as having occurred before. Moreover, it is rare to find a situation in which (a) an amputee demonstrates amnesia or forgetting (of the contents of the cognitive memory component) and (b) an independent source had verified the nature of the pain at the time of injury before amputation.

Nevertheless, there are several lines of evidence supporting dissociation of this kind, both animal (Katz, Vaccarino,Coderre, & Melzack, 1991) and human (Lacroix, Melzack, Smith, & Mitchell, 1992). Lacroix et al. reported the case of a 16-year-old girl who was born with a congenital deformity of the right foot, which was amputated when she was just 6 years old. At the time of the interview, 10 years after amputation, the patient reported a flat phantom foot that was stuck in a forward position. This description corresponded to information subsequently obtained from her medical records verifying a right flatfoot that was locked in an equinovalgus position and incapable of movement. Interestingly, the patient was not aware that her foot had been deformed as a child, for she mistakenly described her foot as she "remembered" it prior to amputation as being normal and

freely mobile. This case report demonstrates the remarkable capacity of the CNS to retain, for years after amputation, a complete representation of the cut-off part, including its somatosensory qualities, proprioceptive sensibility, and associated motor program. Moreover, the case demonstrates that the neural circuitry underlying the somatosensory component is capable of being activated and of influencing conscious awareness independent of the cognitive component.

Although separate representations of the somatosensory and cognitive components are formed during repeated occurrences of the preamputation pain, such frequent and temporally contiguous activity would result in a tendency for these representations to occur more often together than alone once the limb has been removed. There is evidence that the two memory systems may be reciprocally connected so that activation of either memory component can lead to activation of the other. The presence of the somatosensory component is sufficient to activate the contents of the cognitive component as implied by the process of recognition involved when a patient identifies the somatosensory qualities of the experience as having occurred before. The possibility also exists that the link is bidirectional. One subject in the study by Katz and Melzack (1990) reported that he could reproduce at will the sensation of the "hole" from a gangrenous ulcer he had on the medial aspect of his foot prior to amputation, but if he did not concentrate on it, the somatosensory component remained out of his awareness. It is important to note, however, that activation of the representation underlying the cognitive component is not to be equated with the conscious awareness of thoughts about the past pain, but when such thoughts occur, excitation of the corresponding neural assemblies must have been involved.

Implications of Separate Memory Components

There are important implications associated with the suggestion that separate somatosensory and cognitive memory systems underlie pain that persists after amputation. For one, conscious awareness of the contents of the cognitive memory component is not necessary for the *reactivation* of the somatosensory component (although it may facilitate the process when present). Second, it is clear that the conscious experience of pain is not a necessary condition for the *formation* of the somatosensory memory component. That is, the formation of the somatosensory component can occur even when there is no conscious awareness of pain at the time of injury or trauma (Katz et al., 1991, 1992, 1994) or when the cognitive component is not accessible through introspection (Lacroix et al., 1992).

These findings raise the possibility that just as brief, intense pain experienced in a limb shortly before its amputation persists as phantom limb

pain memory (Katz & Melzack, 1990), the effects of the primary afferent "injury discharge" on spinal cord dorsal horn neurons produced by surgical incision (and subsequent cutting of muscle, nerve, and bone) may also produce lasting changes that later contribute to postoperative pain. This implies that both somatosensory and cognitive systems must be blocked in order to interfere with the formation of a pain memory arising from the surgical procedure (Fig. 19.3).

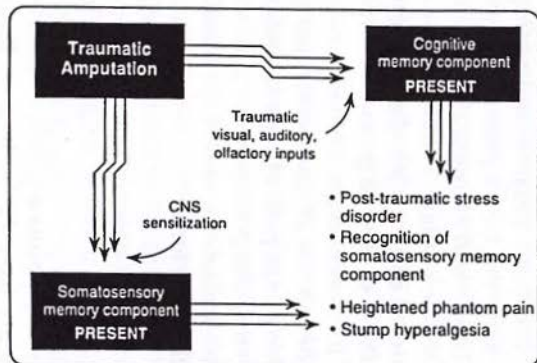
Patients who have sustained traumatic amputation either by accident, combat-related injury, or emergency surgical procedures carried out without anesthetics or analgesics (e.g., in war-ravaged parts of the world) are at highest risk for developing postamputation problems (Fig. 19.3a). Traumatic amputation would be expected to result in the formation of both the somatosensory and cognitive memory components. The expected outcome would include heightened stump pain (stump hyperalgesia), heightened phantom limb pain intensity, recognition of the somatosensory qualities of the pain, and a posttraumatic stress disorder arising from the traumatic events.

Amputation performed under general anesthesia alone (Fig. 19.3b) would interfere with the formation of the *cognitive* but not the *somatosensory* memory component. However, unlike a pain memory that resembles a long-standing preamputation lesion, the somatosensory qualities of post-surgical pain would not be recognized by a patient whose surgery was performed under a general anesthetic, because the patient would not have had any conscious experience of pain at the time of incision and amputation. Upon awakening from the general anesthetic, the patient's complaints of pain would reflect the persistent central neural memory trace left by the surgical procedure in addition to input from transected fibers in the amputation stump (Wall, 1989). This is hypothesized to result in enhanced postoperative phantom limb pain and heightened pain at the site of the incision (incisional hyperalgesia).

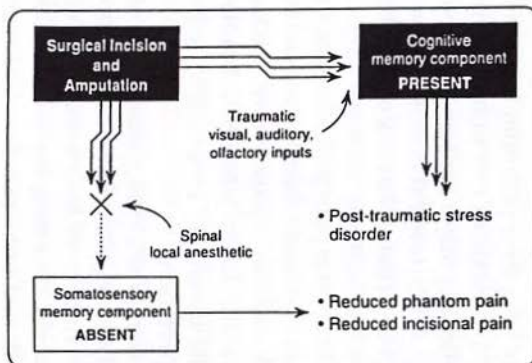
Administration of spinal local anesthesia alone (Fig. 19.3c) would block the formation of the *somatosensory* but not the *cognitive* memory component. The preincisional spinal blockade would prevent the injury barrage from reaching the CNS, resulting in less intense postoperative phantom limb pain and incisional pain. However, in the absence of a general anesthetic, awareness during amputation can produce vivid declarative memories of operating room events that develop into a posttraumatic stress disorder.

Combined use of spinal anesthesia and general anesthesia (Fig. 19.3d) would be expected to interfere with both *somatosensory* and *cognitive* memory systems by blocking the transmission of nociceptive impulses (arising from the cutting of tissue, nerve, and bone) at the level of the spinal cord, and by ensuring that the patient is unconscious during the surgical procedure. This model has yet to be tested in patients undergoing amputation.

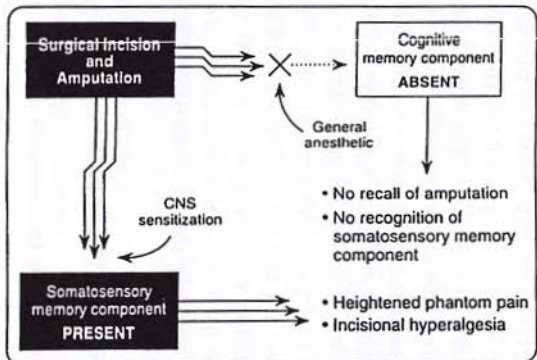
A. Traumatic Amputation



C. Spinal Anesthesia



B. General Anesthesia



D. Combined Spinal Plus General Anesthesia

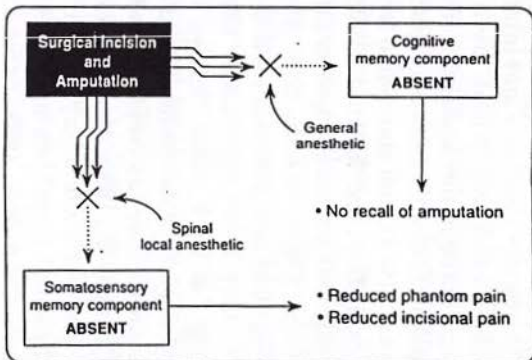


FIG. 19.3. Predicted postoperative pain status and psychological status following traumatic amputation or surgical amputation performed under general anesthesia, spinal local anesthesia, or combined spinal local anesthesia plus general anesthesia (see text for details).

Preemptive Analgesia and Other Preventive Approaches to Phantom Limb Pain

Preemptive and other preventive approaches have considerable potential for reducing the incidence and intensity of long-term phantom limb pain, but well-designed clinical trials are required to establish this with certainty. Short-term preemptive analgesic effects following major surgery have been reported for lateral thoracotomy (Katz et al., 1992), lower abdominal surgery (Katz et al., 1994), and abdominal hysterectomy (Katz, Clairoux et al., 1996; Richmond, Bromley, & Woolf, 1993), but the majority of these surgical procedures are not usually associated with long-term pain problems. On the other hand, long-term reductions in phantom limb pain have been reported when regional analgesia was used to block noxious inputs before, during, and/or after limb amputation (Bach et al., 1988; Jahangiri, Bradley, Jayatunga, & Dark, 1994; Schug, Burrell, Payne, & Tester, 1995), but methodological problems limit valid interpretation.

The prospective intervention studies (Bach et al., 1988; Jahangiri et al., 1994; Schug et al., 1995) provide some of the strongest evidence supporting a link between acute injury and the development of long-term phantom limb. Epidural anesthesia started before and continuing for the duration of surgery (Bach et al., 1988) or for several days after amputation (Jahangiri et al., 1994; Schug et al., 1995) appears to confer the most protection from long-term pain. By contrast, blockade of late intraoperative and postoperative noxious inputs does not seem to alter the developmental course of persistent pain (Elizaga, Smith, Sharar, Edwards, & Hansen, 1994; Fisher & Meller, 1991), probably because the blockade is administered after central sensitization has been established. As noted earlier, a number of methodological problems limit the validity of these studies (e.g., small sample sizes, nonrandom assignment of patients to treatment, nonblinded treatment and pain assessment, insufficient details about pain assessment). Discovering the relative contributions to long-term pain of factors such as preexisting pain, noxious perioperative events, and postoperative pain will enable us to design multiagent, preemptive treatments aimed specifically at minimizing the detrimental effects of these factors.

PHANTOM PARALYSIS

Phantom limb movements are reported by approximately 36% of patients 8 days after amputation and by 24% 2 years later (T. S. Jensen, Krebs, Nielsen, & Rasmussen, 1984). In contrast, we do not know the percentage of amputees who report that their phantom is "frozen" in a fixed posture, incapable of voluntary movement. For some amputees, the problem of "phantom paralysis" is associated with pain (Ramachandran, 1994). For example, a common report is that the amputee's fingernails are felt to be

digging into the palm of the phantom hand (Mitchell, 1872; Ramachandran, 1994; Ramachandran & Rogers-Ramachandran, 1996). In some cases this may be related to the position of the limb before amputation (i.e., a postural pain memory) (Browder & Gallagher, 1948; Frederiks, 1963; T. S. Jensen & Rasmussen, 1994; Katz & Melzack, 1990; Mitchell, 1872; Riddoch, 1941). In others, the inability to move the phantom limb may develop progressively after amputation (Ramachandran, 1994; Ramachandran & Rogers-Ramachandran, 1996). Until recently, there has been nothing in the way of treatment for this painful problem.

A clever solution has been devised that promises to restore, at least temporarily, a sense of voluntary movement to the paralyzed phantom limb (Ramachandran, 1994; Ramachandran & Rogers-Ramachandran, 1996). The solution is based on the assumption that the brain has "learned" that the phantom is paralyzed. The learning occurs either as a function of past experience with a paralyzed limb before amputation or subsequent to amputation due to the absence of visual feedback from the limb following attempts to move the phantom. The experiments involve a "virtual reality box" that makes use of mirrors to trick the brain into thinking that the phantom is moving. The amputee looks into a mirror at the reflection of his or her contralateral intact hand while it is positioned to coincide spatially with the felt position of the phantom hand. The amputee is then instructed to carry out the same movement with both hands while looking at the phantom (i.e., the reflection of the intact hand). In the majority of cases, the sight of the hand moving determines the ultimate perception, and the amputee feels as if the once paralyzed hand is now moving freely. These findings support the idea that vision dominates over other sensory modalities in determining the phantom limb percept (Katz, 1993). When there is a discrepancy or contradiction between incoming information from different modalities, or when a state of uncertainty exists based on somatosensory input alone, additional information is sought via the visual sense, which usually determines the perceptual experience.

The initial experiments carried out by Ramachandran and colleagues (Ramachandran, 1994; Ramachandran & Rogers-Ramachandran, 1996) suggest that in most cases the initiation of movement in the phantom is also associated with pain relief. From a clinical standpoint, controlled studies are needed to assess the duration of the analgesic effect, the percentage of patients in whom it is effective and the possibility that a permanent effect can be achieved with repeated use of the mirrors.

CONCLUSIONS

The material presented in this chapter indicates that the phantom limb is not perceived as a static entity but as a frequently changing perceptual experience. Phantom limb phenomena range from simple, diffuse sensa-

tions of tingling to perceptually complex experiences of pains and lesions that originally were felt in the limb prior to amputation. Although phantom pains and other sensations frequently are triggered by the perception of salient events, thoughts, and feelings, there is no evidence that the painful or painless phantom limb is a symptom of a psychological disorder. The sympathetic nervous system may provide an important link between higher brain centers involved in cognitive and affective processes and phantom limb sensations through its peripheral actions on primary afferents located in stump neuromas. Pharmacological and nonpharmacological treatments geared toward reducing sympathetic outflow may prove effective in managing phantom limb pain for some amputees. Other qualities of phantom limb pain may be generated by different mechanisms. Thorough evaluation of patients is essential to isolate relevant mechanisms. Treatment options may include temperature biofeedback for burning phantom limb pain and muscle tension biofeedback for cramping phantom limb pain. Preamputation pain should be reduced as soon as possible to avoid the development of a pain memory. Preoperative and intraoperative spinal or epidural analgesia is expected to block the injury discharge associated with noxious surgical events and lead to a reduced incidence and intensity of phantom limb pain. Immobilized or paralyzed phantoms may acquire the capacity to move following restoration of visual information of the limb created by use of mirrors.

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